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PROJECT TECHNICAL REPORT

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FINAL ANALYSIS  
OF THE DESCENT PROPULSION SYSTEM  
DURING THE FLIGHT OF APOLLO 5

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NAS 9-4810

22 March 1968

Prepared for  
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION  
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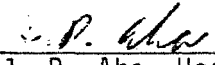
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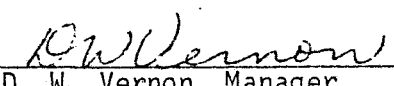
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## CONTENTS

	<u>Page</u>
1. SUMMARY.....	1
2. DPS SYSTEM AND MISSION DESCRIPTION.....	2-1
2.1 DPS System Mission Description.....	2-1
2.1.1 Primary Apollo 5 Mission.....	2-1
2.1.2 Apollo 5 Mission As Accomplished.....	2-1
2.2 DPS System Description.....	2-2
3. DPS TRANSIENT OPERATION.....	3-1
3.1 General.....	3-1
3.2 DPS Burn Times.....	3-1
3.3 DPS Start Transients.....	3-2
3.4 DPS Shutdown Transients.....	3-5
3.5 DPS Throttle Response.....	3-6
4. SUMMARY OF STEADY STATE PROPULSION PERFORMANCE.....	4-1
4.1 Steady State Performance.....	4-2
4.1 Flight Data For Apollo 5.....	4-3
4.2 DPS Phasing Anomaly.....	4-5
4.3 Propellant Quantity Gauging System.....	4-9
5. SUPERCRITICAL HELIUM PRESSURIZATION SYSTEM.....	4-9

## LIST OF TABLES

### TABLE

1	DPS Burn Times.....	T-1
2	DPS Transient Impulse Summary .....	T-2
3	Comparison of DPS FTP System Pressures From Ground Test, Flight, and Model Simulations.....	T-3
4	Summary of Apollo Failure Reports Concerning Position Switches.....	T-4
5	Summary of Apollo Failure Reports Concerning Pilot Solenoid Valves.....	T-5
6	Supercritical Helium Supply System Heat Exchanger Performance.....	T-6

# CONTENTS (CONT'D)

## ILLUSTRATIONS

FIGURE		<u>Page</u>
1	DPS Chamber Pressure During Start.....	F-1
2	LM-1 DPS Second Burn.....	F-2
3	LM-1 DPS Third Burn.....	F-3
4	DPS Second Burn Throttle Switchover.....	F-4
5	Descent Propulsion Subsystem Supercritical Helium Supercritical Helium Supply Tank Pressure Burn 1..	F-5
6	Descent Propulsion Subsystem Supercritical Helium Supply Tank Pressure Burn 2.....	F-6
7	Descent Propulsion Subsystem Supercritical Helium Supply Tank Pressure Burn 3.....	F-7
8	Descent Propulsion Subsystem Supercritical Helium Supply Tank Pressure Burn Through 3.....	F-8

## 1.0 SUMMARY

On 22 January 1968 at 22:48.08 Greenwich Mean Time (G.M.T.), the Apollo 5 Mission began with the launching of the uprated Saturn 1B launch vehicle. Insertion into orbit was at 00:10:03.3 Ground Elapsed Time (G.E.T.) and the first Descent Propulsion System (DPS) was attempted at 03:59:41 (G.E.T.). A premature LGC cutoff signal was given after the first 4 seconds of the first Descent Propulsion System burn, and an Alternate Mission C was implemented using Program Reader Assembly (PRA)-III. Mission C consisted of two burns separated by a 35 second coast period and, at the end of the third Descent Propulsion System burn, abort staging was commanded.

Analysis indicated that all Descent Propulsion System starts were normal for imposed flight conditions and LEM Guidance Computer (LGC) cutoff of the first burn was verified, based on the criterion used in the computer. This criterion is not necessary for the operation of the propulsion system and from this standpoint it is recommended that it be eliminated.

An out of phase indication on the shutoff valves was observed on both the second and third burns of the descent engine. This anomaly was due to either a shutoff valve leaving the full open stop or to a malfunction of a valve position indication switch. The probable cause was attributed to pilot valve leakage causing the shutoff valve to close when the engine was commanded to the full throttle position.

No analysis was made concerning a minimum variance estimate of engine performance as the propulsion system firing durations were not long enough to obtain an adequate amount of data. The operation of the supercritical helium pressurizing system appeared to be normal for the burn durations, however, more operating time in a space environment is required to verify that the system is satisfactory for the Lunar Landing Mission.

## 2.0 DPS SYSTEM AND MISSION DESCRIPTION

### 2.1 DPS SYSTEM MISSION DESCRIPTION

#### 2.1.1 PRIMARY APOLLO 5 MISSION

Two DPS burn were planned for the Primary Apollo flight to simulate a mission duty cycle.

The first DPS burn was planned to occur on the third revolution in an attitude hold mode. An 8 second RCS + X axis translation was initiated to provide ullage settling, and the RCS maneuver was to be terminated 0.5 seconds after the DPS fire command. Then the DPS 10% thrust level was to be maintained for 26 seconds after which the thrust was to be increased to Fixed Throttle Position (FTP) (94%) for approximately 12 seconds until guidance cutoff.

Following an orbital coast of approximately 33 minutes, orientation for the second DPS burn was to occur, and 203 seconds later an 8 second RCS + X translation was to be initiated to provide ullage settling. The RCS maneuver was to be terminated 0.5 seconds after DPS fire signal. The start sequence phase was to involve a 26 second burn at 10% thrust followed by 322 seconds at FTP (94%). The engine was then to be throttled to 50% thrust level for 119 seconds. Additional throttling was to occur through a ramped decrease in thrust level from 50% to 20% over a period of 175 seconds. Next, a simulated random throttling phase (consisting of 5 throttle settings each for 10 seconds) was to then occur with settings of 10%, 50%, 30%, 40% and 20%, respectively. At the end of this phase, the throttle position was to be increased to FTP for two seconds to be followed by the APS FTTH Abort.

#### 2.1.2 APOLLO 5 MISSION AS ACCOMPLISHED

After LM extraction, the LM was oriented for the first DPS burn of the Primary Apollo 5 Mission. On the third revolution at 03:59:33.9, a RCS + X maneuver was initiated to provide ullage settling. At 03:59:41 the fire signal for the DPS initiated the first DPS burn, and at 03:59:45 the DPS engine was prematurely cutoff by the LGC.

Following the guidance commanded shutdown, four seconds after the fire signal for the first DPS burn, the decision was made to implement alternate Mission C.

In preparation for the second DPS burn under alternate Mission C on the fifth revolution, the RCS +X ullage maneuver was initiated at 06:10:33.4. At 06:10:41, the fire signal commanded the second DPS burn and the RCS ullage maneuver was terminated at 06:11:51.3. After approximately 26 seconds at 10% thrust the engine was throttled to the FTP (94%) for 7 seconds. The second DPS burn was commanded off at 06:11:14 seconds.

After a 24 second coast a RCS +X ullage maneuver was initiated at 06:11:38.4. Approximately 10 seconds later the command for the third DPS burn at 06:11:46 seconds. Five seconds later the RCS ullage maneuver was terminated. After 26 seconds at 10% thrust the DPS was commanded to the FTP for approximately two seconds in preparation for the APS FIFTH Abort. The DPS engine off signal was commanded at 06:12:14 G.E.T.

## 2.2 DPS SYSTEM DESCRIPTION

The LM-1 propulsion system is identical to the LM-3 baseline propulsion system with the following exceptions.

- 1) The LM-1 pressurization system does not contain the ambient start bottle.
- 2) The brazing process used for the helium heat exchanger is different from that which will be used on subsequent LM Vehicles.
- 3) Propellant tank lunar surface venting capability was not installed on LM-1.

The baseline propulsion configuration differs from the operational configuration by the addition of the development flight instrumentation and telemetry package.

The LM-1 contained a LM Mission Programmer instead of a crew. The LM Mission Programmer is a semi-automatic package in which ground commands or LM Guidance Computer commands enable control normally provided by the astronauts.

### 3.0 DPS TRANSIENT OPERATION

#### 3.1 GENERAL

An analysis was made of the DPS start, shutdown and throttling transients to verify satisfactory transient operation. Because of the unexpected LGC cutoff of the first DPS burn (DPS 1), particular attention was given to analyzing the engine transient operation during that burn. The transient analyses for all three burns were hindered by several data problems. These problems consisted mainly of magnitude disagreements between PCM and FM/FM data, and timing errors with digitized FM/FM data. However, in most cases, it was possible to adjust the questionable data, based on other data and ground test experience, to more reasonable values. The absence of high sample rate data from the DPS engine start/cutoff command signal (GH 1301 X @1 s/s) and from the throttle command voltage (GH 1311 V @1 s/s and GH 1331 V @ 10 s/s) made it necessary to estimate engine start, cutoff and FTP command times by indirect means.

#### 3.2 DPS BURN TIMES

Table 1 contains the estimated start, shutdown and FTP command times for each DPS burn. The start times for each burn are based on the RCS "X" translation event times as determined from measurements GH 1419V, GH 1423V, GH 1427V and GH 1431V. This method was considered most accurate because these measurements were available on PCM at 200 s/s. The planned time differentials from DPS engine start to "RCS 'X' translation off" were subtracted from the "RCS 'X' translation off" times determined from the above four measurements to give the estimated DPS start times. For the DPS 1 burn, the "RCS 'X' translation off" was programmed in the LGC to occur 0.5 seconds after DPS start command. For the DPS 2 and DPS 3 burns the planned "RCS 'X' translation off" time in the alternate mission (PRA III) was 5.0 seconds after DPS start command. The start times determined in this manner correlated very well (See Table 1) with the times at which the first drop in fuel interface pressure was noted on the oscillogram records (measurement GQ 3611P, continuous FM/FM). The drop in fuel interface pressure at engine start results from fuel flow through the shutoff valve pilot valves, and has a very small, and repeatable, time delay (0.025 seconds during acceptance tests) after start signal.

The DPS 1 cutoff time was estimated by adding the burn time from the LGC downlink data to the estimated start time. The DPS 2 and DPS 3 cutoff

times were estimated from the RCS event times and the alternate mission (PRA III) burn times similar to the way the start times were determined. The estimated start and cutoff times are all consistent with the start and cutoff times from the 1 s/s measurement GH 1301X, and are consistent with the time histories of the other DPS parameters. The DPS 3 cutoff time was further verified by the abort stage command, GH 1283X PCM @ 50 s/s).

The FTP command times during both the DPS 2 and DPS 3 burns were estimated by adding the planned alternate mission (PRA III) time differentials to the estimated start times. As shown in Table 1, these estimated FTP command times agree well with both the actuator position (feedback voltage) GQ 6806H and the chamber pressure start-to-rise time from GQ 6510P.

### 3.3 DPS START TRANSIENTS

The start command for the first DPS burn was given by the LGC at 3:59:41.34 G.E.T. The first DPS burn was terminated by the LGC approximately four seconds after start command (about 32 sec. earlier than expected). The LGC commanded cutoff because certain programmed  $\Delta V$ /time criteria were not satisfied. The LGC was programmed to verify satisfactory DPS thrusting by comparing the  $\Delta V$  gained, over two second intervals, to a preset minimum value (0.45 m/sec for LM-1). This was essentially an average acceleration test. The LGC computed the resultant vehicle  $\Delta V$  gained over each two second interval starting 30 seconds prior to the planned start command time. At the end of each two second interval following the engine "ON" command, the  $\Delta V$  gained was compared to the preset value. If the  $\Delta V$  gained failed to equal the minimum for a specified number of check intervals, the LGC would command cutoff. This condition existed for the DPS 1 start and the LGC commanded cutoff 4.17 seconds after engine start command.

Based on the predicted LM-1 weight at DPS 1 ignition, the required  $\Delta V$  gain to satisfy the LGC test described above represents an average thrust of about 720 lbf for a two second interval, or approximately 1440 lbf-sec of impulse.

Figure 1 shows the DPS engine chamber pressure during the three DPS starts. The DPS 1 chamber pressure transient is seen to be slower than either DPS 2 or DPS 3, and is also slower than the nominal (S/N 1026 acceptance tests). The time to 90% of that chamber pressure which existed at

cutoff was approximately 3.8 seconds. The slower DPS 1 start was found to be normal for the interface pressure conditions under which the engine was started. The engine interface pressures at start were approximately 119 psia for the oxidizer and 132 psia for the fuel. The normal starting pressures for the DPS engine are between 242 psia (specified minimum regulator outlet pressure) and 253 psia (maximum regulator lock-up pressure). The nominal data shown in Figure 1 were obtained during tests with starting pressures of approximately 242 psia. The starting pressure for DPS 2 and DPS 3 were approximately 242 psia for both oxidizer and fuel. It is, therefore, apparent that the interface pressures at the DPS 1 start were significantly lower than normal. The low interface pressures at start resulted from lower than nominal propellant tank ullage pressures. At DPS 1 start, the supercritical helium pressurization had not yet been initiated and the propellant tank ullages contained only lockup ground pressurization helium. The ground pressurization level was approximately 145 psia, as called for at a propellant temperature of 70°F. Since LM-1 was flown without the ambient helium start bottle, there was no additional pre-ignition ullage pressurization, and the ullage pressures at DPS 1 start were well below nominal.

Helium pressurization was initiated approximately 1.1 seconds after DPS 1 start command. The interface pressures then started to rise, but had not reached the nominal 235 psia when cutoff was commanded. The interface pressures at cutoff were approximately 185 psia for oxidizer and 202 psia for fuel. Because of this pressurization system transient, the engine did not reach a steady-state condition during the first burn.

The engine start time is a function of the interface pressures. Lower interface pressures reduce the flowrates and thereby increase the time required to fully prime the propellant lines and injector manifolds downstream of the shutoff valves. Low fuel interface pressure also increases shutoff valve opening times since they are fuel pressure actuated. Analytical simulations using a simplified start model indicate the time to 90% of steady-state chamber pressure for a 10% start should be at least a second longer than nominal for the interface pressures experienced during the DPS 1 burn. Throughout the text this value of 10% is used to refer to this level which is actually 12.4%. A special test (PD2-7-033) was conducted at WSTF follow-

ing the flight to simulate the DPS 1 start. The chamber pressure during that test is also shown in Figure 1, and verifies that the longer start time for DPS 1 is normal. The WSTF test was started with interface pressures of 127 psia fuel and 132 psia oxidizer with supercritical helium pressurization being initiated 0.91 seconds after start command.

The start impulse for DPS 1, from start command time to cutoff signal, was approximately 1075 lbf-secs. As noted before, the LGC  $\Delta V$  criteria required an impulse of approximately 1440 lbf-secs over a two second interval, therefore, the engine data verified that the LGC  $\Delta V$  requirement was not met within 4 seconds.

Following the early DPS 1 cutoff, control was switched from the LGC to PRA III. The DPS 2 burn was initiated by PRA III at 6:10:41.29 G.E.T. The DPS engine chamber pressure during start is shown in Figure 1, and is seen to be very close to nominal. As stated earlier, the interface pressures at the start of the DPS 2 burn were approximately 242 psia, which is within the nominal range.

The DPS 2 start impulse from start command to 90% of steady-state thrust was 894 lbf-sec. The time from start command to 90% thrust was 2.66 seconds, which is within the specified maximum time of 4.0 seconds.

PRA III initiated the DPS 3 start at 6:11:46.29 G.E.T. The DPS 3 chamber pressure during start, Figure 1, rose slightly faster than for both DPS 2 and nominal. The time from start command to 90% of steady-state thrust was 2.13 seconds. This slightly quicker start may have resulted from the fuel injector manifold still being partially primed from the DPS 2 burn, which ended only 32 seconds before DPS 3 start.

The DPS 3 start impulse from start command to 90% of steady-state was 574 lbf-secs.

The DPS engine specification requires that the start impulse be repeatable to provide predictable total impulse accuracy of  $\pm 100$  lbf-seconds. The mean start impulse for the DPS 2 and DPS 3 burns was 734 lbf-seconds. Each burn deviated from the mean by 160 lbf-seconds, which exceeds the specified  $\pm 100$  lbf-seconds tolerance. However, it is felt that this specification, which was originally established for FTP starts, should be re-examined for low thrust starts and, to be applicable, sufficient time

between burns should be allowed to assure that the injector manifolds are empty. Ground testing has demonstrated that the start impulse during low thrust starts is less repeatable than during FTP starts. Based on ground test results, it is felt that the start-impulse repeatability for LM-1 was satisfactory. It is recommended that the specification governing start impulse be clarified for low thrust starts.

Chamber pressure disturbances noted during the DPS 2 start transient (1.6 to 1.9 seconds after the start command) were within the specified maximum level of 200% of steady state and are considered normal.

The transient characteristics for DPS 2 and DPS 3 are tabulated in Table 2 along with the corresponding ground test and specification values.

#### 3.4 DPS SHUTDOWN TRANSIENTS

The DPS 1 cutoff was commanded by the LGC at 3:59:45.51 G.E.T. Since steady-state thrust was never achieved during the DPS 1 burn, the shutdown impulse was not computed.

The DPS 2 cutoff was initiated by PRA III at 6:11:14.29 G.E.T. The shutdown impulse from cutoff signal to 10% of the thrust at cutoff was 1727 lbf-sec. The time to 10% thrust from cutoff signal was 0.26 seconds. The time to 10% thrust is 0.01 seconds longer than the specified 0.25 seconds, however, allowing for the tolerances on the data used, the shutdown transient is considered to be satisfactory.

The total shutdown impulse for the DPS 2 burn was also determined from the change of velocity imparted to the spacecraft after the shutdown signal was initiated. The results yield an impulse of approximately 2493 lb-sec. The corresponding impulse determined by integration of the chamber pressure from the shutoff signal to zero pressure yields a total cutoff impulse of approximately 2329 lb-secs.

PRA III commanded the DPS 3 burn cutoff at 6:12:14.31 G.E.T. The 10% thrust shutdown impulse was 1713 lbf-sec. This is within the specified repeatability criteria of 100 lbf-sec.

The time to 10% thrust from cutoff signal was 0.30 seconds which is 0.05 seconds longer than specified. The difference in shutdown time could be due to instrumentation-data reduction errors, differences in shutdown

characteristics caused by the space environment, or a combination of these effects. In either case the discrepancy does not appear to be unacceptable and future flight tests should provide additional information in this area.

### 3.5 DPS THROTTLE RESPONSE

During the second DPS burn the PRA III commanded the DPS engine from the 10% thrust level to FTP at 6:11:07.29 G.E.T. Figure 4 shows the time history of the chamber pressure and injector actuator position during the transient to FTP. The engine reached the FTP thrust level 0.40 seconds after the command was initiated. The chamber pressure was within 5 psia of the FTP chamber pressure 0.34 seconds after the command. During engine acceptance tests, the time to within 5 psia of the FTP chamber pressure was 0.346 seconds. Specifications allow for a maximum response time of 1.0 seconds from  $F_{min.}$  to  $F_{max.}$  The intermediate chamber pressure plateau occurring during the throttling operation as shown in Figure 4 is discussed in subsequent sections.

During DPS 3, the PRA III commanded the engine to FTP at 6:12:12.29 G.E.T. As in the second burn, the throttle response time was 0.40 seconds. It is thus concluded that the throttle response during both burns was acceptable.

#### 4.0 SUMMARY OF STEADY STATE PROPULSION PERFORMANCE

An investigation was conducted on the propulsion subsystem performance and the results are presented herein. These results show that insufficient data were obtained from the Apollo 5 Mission to determine the performance of the propulsion or supercritical helium subsystem because of the short burn durations.

An indicated DPS valve phasing anomaly on DPS 2 and DPS 3 could not be resolved because of the telemetry data available on valve operation. However, the cause was attributed to either a pilot valve or reed switch malfunction. This area needs additional investigation and/or testing at simulated flight conditions before more positive results can be obtained. It should be noted that a single electrical connector carries the dual electrical signal to the pilot valves, which actuate the shutoff valves; this area should be reviewed from the standpoint of reliability.

The DPS 1 burn was terminated by an LGC cutoff criterion. The need for this criterion should be reviewed because it is not compatible with the starting sequence of the engine. From the standpoint of propulsion system operation, this criterion is not required.

#### 4.1 STEADY STATE PERFORMANCE

Thrust chamber pressure-time histories are presented in Figures 2 and 3 for the second and third DPS burns. These plots are a compilation of the PCM and FM data and where discrepancies existed PCM measured pressure levels and FM measured times were used.

No statistical analysis of the flight data was made to determine the best estimate of performance parameters. The statistical analysis was omitted because the engine burn duration was not long enough to determine system performance from acceleration data. The sample rate of acceleration data was one sample per two seconds and, as a result, only eleven acceleration points were received for the second burn, of which only two were at FTP. The number of acceleration points for the third burn was even fewer.

The problem of performance determination was compounded also by the fact that total propellant consumption was quite low. As a result, the total deflection of the gauging system was within the measurement instrument accuracy; and in fact was affected by what could appear to be sloshing. The inability to determine propulsion system performance during flight precludes any possibility of improving upon performance estimates derived from ground test data. The analysis was therefore deleted.

On the following page is a table of some flight measurements showing pressure levels within the engine feed system, representative of average values during DPS 2. The lower portion of this table presents the flight data with obvious biases removed.

FLIGHT DATA FROM APOLLO 5

TIME	PARAMETER			
	Helium Reg. Outlet Press (GQ3018P) psia	Engine Ox Interf. Press (GQ4111P) psia	Engine Fuel Interf. Press (GQ3611P) psia	Thurst Chamber Pressure (GQ6510P) psia
Uncorrect Flight Data				
Before Ignition	241.9	249.0	241.9	0.8
Ten Percent Thrust	239.5	246.6	239.5	13.4
Full Throttle Position	239.5	227.7	214.6	103.6
Bias Corrected Flight Data				
Before Ignition	241.9	241.9	241.9	0
Ten Percent Thrust	239.5	239.5	239.5	12.6
Full Throttle Position	239.5	220.5	216	102.8

The measurement biases were noted in the chamber pressure, and oxidizer interface pressure were +0.8 psi and +7 psi, respectively. In addition, it was observed that fuel ullage pressure was biased about +11 psi. This conclusion was reached from pressure measurements taken during coast period. During these times it was noted that the fuel interface pressure was identical to the regulator outlet pressure, and at a corresponding time the fuel ullage pressure was higher than both. As the ullage pressure measurement is between the regulator and interface, it was concluded that the measurement was in error.

Also noted in the analysis of the data was a possible bias in fuel interface pressure at the full throttle position. Since there exists evidence to indicate that the transducer was reading correctly during coast, the measurement during engine burn is not assumed to be biased. It is speculated that the low pressure may be due to leakage, increased flow resistance, or incorrect orificing of the feed system. A candidate leakage hypothesis is discussed in subsequent paragraphs.

A preliminary analysis also suggested the possibility of freezing the fuel in the fuel-helium heat exchanger as the cause of the low pressures measured at the fuel interface. It could be suggested that the fuel partially froze at DPS 1 or, during the coast period between the first and second burns, thus decreasing the flow area in the heat exchanger. This decrease would result in an increased resistance, and consequently a low fuel interface pressure. This possibility of freezing has not been borne out by the temperature data or by fuel interface transient behavior, and the results of an approximate heat transfer calculation did not indicate the likelihood of freezing. This analysis however does not preclude either a calibration bias or some unknown flow resistance between tank and ullage since these are possibilities that cannot be ruled out on the basis of the flight data.

The chamber pressure levels shown in the previous data table were also confirmed utilizing an analytical model of the DPS in conjunction with measured interface pressures and reported propellant densities of 89.926 lbm/ft<sup>3</sup> for oxidizer and 56.564 lbm/ft<sup>3</sup> for fuel. The resulting calculated chamber pressures were 13.1 and 104.1 psia at the 10% and FTP as compared to the corrected measured values of 12.6 and 102.8 psia during the second DPS burn. The chamber pressure levels for the third burn of the DPS engine were very close to those of the second burn.

#### 4.2 DPS PHASING ANOMALY

On both the DPS 2 and DPS 3 burns instrumentation parameter GQ 7498U, "Shutoff A/B Delta Position," indicated an out-of-synchronization of the A/B ball valves as the descent engine was commanded from 10 percent thrust to full throttle position (FTP). Synchronization was indicated on the first DPS burn and at the start and cutoff of DPS 2 and DPS 3. The indicated anomaly persisted during the full thrust portion of DPS 2 and DPS 3.

The bilevel event shutoff valve position measurement indicated an out of synchronization condition about 400 milliseconds after initiation of throttle command from 10% to FTP. This behavior was observed in both the second and third DPS burns, which were the only burns in which this throttle command was given. Figure 4 presents the time history of the transients for the shutoff valve position measurement and for several engine pressures. Only the DPS second burn is presented since the transient behavior for both burns was quite similar.

After initiation of the throttle command, the interface, injector inlet, and thrust chamber pressure traces show that the throttling proceeded normally to approximately 70% chamber pressure during the first 150 milliseconds. At this time, which is about 120 milliseconds before the A/B shutoff valve bilevel indicated that the A or B valve left the open position, a plateau occurred in the pressure traces. In addition, the interface pressures showed a spike or pressure transient which covered about 70-80 milliseconds, as shown in Figure 4. Over this same 70-80 millisecond period, the injector inlet and thrust chamber pressures were seen to level off and remain nearly constant at a pressure corresponding to about 70% thrust. The 70% point is also about the level at which the venturi's normally switch from cavitating to non-cavitating operation. Subsequent to the 70-80 millisecond period, the pressures resumed their normal pattern, although the rates of pressure change were reduced from the initial part of the transient. Steady state operation is reached about 400 milliseconds after initiation of the throttle command.

The indicated behavior of the pressure traces during the middle part of the transient apparently has not been observed during ground tests. Oscillograms from the acceptance tests of DPS Engine S/N 1026 show that the interface pressures decreased, rather than increased during the middle part of the transient. The downstream pressures observed on the acceptance test showed a hesitation

in the rate of pressure increase, however, the change was not as pronounced as in the flight data. Also, the ground test plateau in pressure rise occurred at almost FTP, rather than at about the 70% level observed in flight. Test data of other engines at WSTF and TRW show a behavior similar to the acceptance test of engine 1026, although the magnitudes of the pressure deflections differ.

A preliminary analysis of the data had indicated that the shutoff valve "not fully open" indication could be attributed to a failure in the instrumentation switches since the steady state pressures reached normal levels. This preliminary conclusion was further solidified by the fact that no pressure disturbances were observed after the valve position change indication. At this point it might be noted that this valve position change indication does not necessarily mean that a shutoff valve went fully closed. The instrumentation circuit is designed to show only that both of the series ball valves are not fully open. Any shift off the fully open position by either or both of the series ball valves could result in the reading observed. Also, because of the manner in which the switches are wired, it is not possible to ascertain whether either valve closed.

Evaluation of the ground test data has shown that changes in the steady state pressure level resulting from closure of one leg of the parallel shut-off valves would not differ greatly from the both-open case, as shown in Table 3.

The first two columns of Table 3 present acceptance test data for Engine S/N 1026 test VA1-361 during which the A/B shutoff valves were closed to simulate a malfunction. The last two columns of Table 3 present analytical model results also simulating the same phenomena. The static pressure data does not allow any significant conclusions to be drawn since the differences in test conditions and instrumentation accuracy could account for the differences in flight and ground test. The analytical model results with valve closure, however, tend to substantiate the flight results. In addition, the pressure drop between the interface and injection pressure was computed for all data and the results are shown in the bottom half in Table 3. The data reveals that the fuel pressure drop remains relatively constant whereas oxidizer pressure drop increases by at least 75% with valve closure. The pressure drop data shows the effects of valve closure better and the results would be a further indication that the valve closed during FTP.

In order to correlate the hydraulic pressures, during the 10% - FTP thrust transients, with the time of the indicated valve closure, similar measurements at shutdown were used. On the DPS 2 and DPS 3 shutdowns a 30-40- millisecond delay was observed between the time the system hydraulic pressures first indicated valve movement and the time the C/D bilevel instrumentation indicated that the valves left the full open position. The time delay is due to the fact that the valves travel up to 30 degrees before an open position drop out is indicated by the reed switches.

If the hydraulic delay is added to a possible 10 millisecond sample rate bias the result would indicate that a pressure disturbance should have been observed 40 to 50 milliseconds prior to the out of phase indication. The observed delay was 120 milliseconds prior to the indication. This would imply that the out of phase indication and the plateauing in the pressure transients are not connected. This conclusion assumes that the A or B valve characteristics at the transient are similar to the C/D valve at cutoff, and does not account for the possibility of one valve closing in a sluggish manner. Nor does the estimation account for the effect of the prevalues closing at shutdown simultaneously with the pilot valves, i.e., the prevalue closing could accelerate the shutdown transient.

The possibility still exists that the valve phasing indication was due to switch failure. However, the measurement did not indicate erratic operation that might accompany such an effect. If it is assumed that the switches operated normally, and therefore, the A or B shutoff valve went closed, or partly closed, the pressure anomalies could also be explained. The causes of such a failure could be fuel leakage in the system or loss of power to the solenoid valve. Though other mechanisms could be investigated these would appear most probable. Of these two, failure of the solenoid seems the less credible since it seems unlikely the solenoid would fail at almost precisely the same time on both FTP burns, and would operate normally for both 10% burns. In addition, the wiring of the solenoids is redundant and would have required simultaneous wire failure. Failure of the power supply would result in deenergizing all solenoid valves, and consequently engine shutdown. Measurement GH 1301X, DPS engine on, which is the command signal of power to the solenoids did not indicate a power failure. A check was made of the power supply amperage and the results were inconclusive in

terms of detecting a solenoid dropout.

A leakage thesis is also a possibility. This thesis would suppose that there exists a fuel leak between the solenoid actuated poppet and the actuator piston, perhaps resulting from a poppet not seating properly. If such a leak existed, it would require that the actuator cavity pressure be above approximately 100 psia at the 10% thrust level and below 100 psia at FTP. The engine fuel interface pressure was 238 psia at 10% thrust and 216 psia at FTP, a difference of 22 psia.

If the decreased pressure at FTP were not sufficient to maintain minimum actuator pressure the shutoff valve would start to close. Parenthetically, it may be noted that a leakage rate would also account for the low measurement of fuel interface pressure and a slow pressure decline within the piston cavity could account for the 80-90 millisecond discrepancy in hydraulic time delay noted earlier.

If such a leak existed, the loss of propellant should have been picked up by the propellant gauging system. It is estimated that delta of about 5 psi at the engine interface would correspond to a leakage flow rate of about 1 to 2 pounds per second. This would result in a fuel loss of 40-100 pounds, depending on the exact flow rate, and the duration of the leak. This would correspond to about a 2% deflection in the gauging system data (GQ 36030). No such deflection was observed. The gauging system data, however, was quite poor, as it showed periods during the second and third burns in which the quantity gauged actually increased by as much as 1%.

The conclusion drawn from the analysis of the synchronization anomaly is that while a case could be made for assigning the phasing indication to switch malfunction, closure of the shutoff valve would be equally if not more plausible.

A survey of Apollo failure reports concerning the shutoff valves was made and the results are shown in Table 4 for the position switches and Table 5 for the solenoid valves. The results show that failure of the open position switches and solenoid vent port leakage are predominating failure modes.

One of the problems encountered in attempting to resolve this out-of-synchronization indication of the shutoff valves are attributable to the

wiring hookup of the eight reed switches. Given only the measurement, as in this case, one is unable to determine on the basis of this bilevel data whether (a) one or both valves or switches left or indicated leaving the open position, or (b) either the A or B valve actually closed. One is able to ascertain only that both valves did not close during the burn. This situation is not desirable and it is recommended that the valve reed switches be re-wired, and telemetered, such that distinct indications are available on each reed switch.

#### 4.3 PROPELLANT QUANTITY GAUGING SYSTEM

The flight data shows that the gauging system in the number two tank of both fuel and oxidizer was not reading correctly. This effect has been attributed to a faulty transistor. The gauging system manufacturer has investigated the failure and substantiated the flight data. Insufficient burn time was obtained on the DPS burns to assess the operation of the gauging system so that no comment can be made on accuracy of the system.

#### 5.0 SUPERCRITICAL HELIUM PRESSURIZATION SYSTEM

An analysis of the performance of the Supercritical Helium Pressurization System (ScHe) on the Apollo 5 Mission during the LM-1 DPS burns has been made. While this analysis is incomplete, it appears as if the ScHe performance was as expected when allowances are made for the initial DPS 1 starting conditions.

In Table 6 the performance of the He/He and He/Fuel heat exchangers is shown. While the temperature profiles of the critical measurements of these subsystems did not exactly follow predictions, the maximum and minimum temperatures recorded at various stations were well within specification limits with minor explainable equations.

The ultimate proof of the ScHe system adequacy lies in its ability to sustain He tank supply pressures (GQ 3435P) sufficient to provide adequate pressurant to the propellant tanks in order that the engine propellant requirements can be met during a LLM. While the DPS burn profiles of Apollo 5 were too short to obtain conclusive evidence to verify this capability, an examination of the tank pressure versus time profiles for each of the DPS burns (see Figures 5 through 8) tends to confirm that the system does perform as expected and within the limits of prediction.

TABLE 1 DPS BURN TIMES

	DPS 1		DPS 2		DPS 3	
	HRS:MIN:SEC	SECONDS	HRS:MIN:SEC	SECONDS	HRS:MIN:SEC	SECONDS
DPS START COMMAND						
1) Best Estimate	3:59:41.34	14381.34	6:10:41.29	22241.29	6:11:46.29	22306.29
2) Based on Fuel Interface Pressure Drop	3:59:41.35	14381.35	6:10:41.29	22241.29	6:11:46.29	22306.29
3) GH 1301X (PCM 1 s/s)	3:59:41.71 <sup>+0.0</sup> <sub>-1.0</sub>	14381.71 <sup>+0.0</sup> <sub>-1.0</sub>	6:10:41.68 <sup>+0.0</sup> <sub>-1.0</sub>	22241.68 <sup>+0.0</sup> <sub>-1.0</sub>	6:11:46.67 <sup>+0.0</sup> <sub>-1.0</sub>	22306.67 <sup>+0.0</sup> <sub>-1.0</sub>
FTP COMMAND	N/A	N/A				
1) Best Estimate			6:11:07.29	22267.29	6:12:12.29	22332.29
2) Actuator Position GQ 6806H (PCM 50 s/s)			6:11:07.32 <sup>+0.0</sup> <sub>-0.2</sub>	22267.32 <sup>+0.0</sup> <sub>-0.2</sub>	6:12:12.32 <sup>+0.0</sup> <sub>-0.2</sub>	22332.32 <sup>+0.0</sup> <sub>-0.2</sub>
3) Chamber Pressure* GQ 6510P (FM/FM 100 s/s)			6:11:07.31 <sup>+0.0</sup> <sub>-0.1</sub>	22267.31 <sup>+0.0</sup> <sub>-0.1</sub>	6:12:12.31 <sup>+0.0</sup> <sub>-0.1</sub>	22332.30 <sup>+0.0</sup> <sub>-0.1</sub>
4) Manual Thrust Command GH 1311V (PCM 1 s/s)			6:11:07.8 <sup>+0.0</sup> <sub>-1.0</sub>	22267.8 <sup>+0.0</sup> <sub>-1.0</sub>	6:12:12.8 <sup>+0.0</sup> <sub>-1.0</sub>	22332.8 <sup>+0.0</sup> <sub>-1.0</sub>
DPS CUTOFF COMMAND						
1) Best Estimate	3:59:45.51	14385.51	6:11:14.29	22274.29	6:12:14.31	22334.31
2) GH 1301X (PCM 1 s/s)	3:59:45.71 <sup>+0.0</sup> <sub>-1.0</sub>	14385.71 <sup>+0.0</sup> <sub>-1.0</sub>	6:11:14.68 <sup>+0.0</sup> <sub>-1.0</sub>	22274.68 <sup>+0.0</sup> <sub>-1.0</sub>	6:12:14.67 <sup>+0.0</sup> <sub>-1.0</sub>	22334.67 <sup>+0.0</sup> <sub>-1.0</sub>
3) Abort Stage Commanded GH 1283X (PCM 50 s/s)	N/A	N/A	N/A	N/A	6:12:14.33 <sup>+0.0</sup> <sub>-0.2</sub>	22334.33 <sup>+0.0</sup> <sub>-0.2</sub>

\*Time of first raise in Pc.

TABLE 2 DPS TRANSIENT IMPULSE SUMMARY

	START IMPULSE FS-1 TO 90%* LB-SEC	TIME FS-1 TO 90% SEC	INTEGRAL OF P <sub>c</sub> FS-1 TO 90% PSI-SEC	SHUTDOWN IMPULSE FS-2 TO 10%** LB-SEC	TIME FS-2 TO 10% SEC	INTEGRAL OF P <sub>c</sub> FS-2 TO 10% PSI-SEC
DPS 2	894***	2.66	9.58	1727	0.26	18.58
DPS 3	574***	2.13	6.20	1713	0.30	18.27
Engine SN 1026	-	2.596	6.25	-	-	-
Acceptance Test 10% Start	-	2.418	7.37	-	-	-
Engine S/N 1026	982	1.314	10.64	-	-	-
Acceptance Test 15% Start	1041	1.360	11.21	-	-	-
Specified Limits	-	4.0	-	-	0.250	-

\*FS-1 indicates engine start command. Integration Limit is 90% of target start thrust level.

\*\*FS-2 indicates engine cutoff command. Integration Limit is 10% of thrust level prior to shutdown.

\*\*\*DPS 2 and DPS 3 were approximately 12.4% (of full thrust) starts.

TABLE 3

## COMPARISON OF DPS FTP SYSTEM PRESSURES

FROM GROUND TEST, FLIGHT, AND MODEL SIMULATIONS

Measurement Parameter	Acceptance Test VA-1		Flight DPS2	Simulation Data	
	Both Open	A/B Closed		Both Open	A/B Failure
Chamber Pressure	102.2	99.8	102.8	103.6	101.1
Oxidizer Interface	219.1	219.5	220.5	220.5	220.5
Fuel Interface	220.0	220.6	216.0	216.0	216.0
Oxidizer Injection	209.8	203.2	206.0	210.7	203.5
Fuel Injection	126.8	122.9	124.0	126.7	123.3
<u>Computed Parameters</u>					
$\Delta P$ Oxidizer Interface-Injection	9.3	16.3	14.5	9.8	17.0 $\pm$
$\Delta P$ Fuel Interface- Injection	93.7	97.7	92.0	89.3	93.7

$$PIO = \pm 4$$

$$PIF = \pm 4$$

116.9

 $\Delta P_{OX}$ 

117.8

INTERFACE - CHAMBER

 $\Delta P_{FI}$

TABLE 4  
SUMMARY OF APOLLO FAILURE REPORTS  
CONCERNING POSITION SWITCHES

<u>Report Number</u>	<u>Problem</u>	<u>Analysis</u>
FST 12750	Slow Response, Open to Close	Roller not adjusted per drawing
FST 12740	C-Position Response Slow	Valve not properly wetted
FST 19119	C-Position Closed Did Not Pull In	Insufficient selectivity in switch magnet
FST 70229	C-Position Open Erratic With Valve Open and Delayed Response	Deflections in Head End--Corrected itself during HATS Test
FST 9527	A Valve Open Switch Does Not Operate	Deflections in Head End
FST 70196	C Valve Open Switch Does Not Indicate	Rack shifted position of magnet 0.004 inch relative to Reed Switch
FST 19120	C Position Open Switch Does Not Indicate During HAT-136	Loss in flux density of Rack Magnet within two weeks
FST 70196	A Position Open Switch Delayed Indication	Poor adjustment
FST 70217	D Position Open Switch Delayed 33 Seconds	Not known--believed insufficient selectivity of switches
FST 70465	C Open Switch Does Not Indicate Properly	Human error in test setup.
FST 19122	B Open Switch Did Not Operation	Burr on rack-mounted Spacer
FST 19123	Position Switch Changed Resistance	Human error
FST 10124	C Open Position Switch Did Not Indicate Open Position	Burr on rack-mounted Spacer
FST 19126	D Open Position Excessive Resistance Pins L to Z	Current overload in resistance check.
FST 19114	D Open Position Switch Drops Out at 32 Degrees Should Be 30 Degrees	Out of tolerance due to vibration phase of valve acceptance test

TABLE 5

## SUMMARY OF APOLLO FAILURE REPORTS CONCERNING PILOT SOLENOID VALVES

<u>Report Number</u>	<u>Problem</u>	<u>Analysis</u>
FST 12150	B Valve Closing Time 5 Seconds Instead of 0.2 Seconds	Wrong solenoid return spring
FST 70023	A Valve Did Not Open on Runs AB5 Through AB8. Did Operate on Subsequent Runs AB9 Through AB21.	Solenoid plunger jammed due to contamination
FST 70103	B Vent Port Leakage at 120-180 Psia While Purging B Valve in Open Position	Leakage past lower seat cause unknown
FST 70108	Popoff Pressure 270 Psi Should Be 375 Psi Minimum	Deflections in the Pilot Valve Assembly
FST 70121	Leakage of 702 CC/HR on D Pilot Valve in the Energized Condition	Contamination of seat
FST 70168	A and D Vent Port Leakage In Open Position	Contamination of seat
FST 70230	Shutoff Valves Remain Open and Will Not Operate	Pilot Valve plungers were stuck closed.
FST 70321	A and D Vent Ports Leak With Valve Closed and 125 to 200 Psig at Actuation Port	Being evaluated
FST 70409	A and D Vent Ports Leak at 280 Psia	Contamination of seat
FST 9251	A and B Vent Ports Leak at 125 Psig With GN2	Contamination (?)
FST 9255	B Vent Port Leaked When Valve in Closed Position	None -- See 70321
FST 12147	C Vent Port Leakage Energized at 150 Psia of 25.2 CC/HR Maximum Allowable is 10 CC/HR	Scratches on seal surface
FST 12148	A and C Vent Port Leakage at 2 Psi of 115 CC/HR and 276 CC/HR	Lower seat leakage due ball seat static O-ring
FST 12509	Pilot Vent Round Up (Leakage)	Nick in valve seats on B and D

TABLE 5 (Cont'd)

## SUMMARY OF APOLLO FAILURE REPORTS CONCERNING PILOT SOLENOID VALVES (Continued)

<u>Report Number</u>	<u>Problem</u>	<u>Analysis</u>
FST 12749	Vent Port Leakage With Unit Energized	Lip of piston stop seal folding over
FST 19196	Intermittant Actuation of C Pilot Valve of 125 Psia With 30 Volts	Unknown cause--solenoid replaced
FST 70101	Maximum Resistance Solenoid Case Receptical 0.015 Ohms, Allowed 0.0025	RES Determined Incorrectly

TABLE 6

## SUPERCRITICAL HELIUM SUPPLY SYSTEM HEAT EXCHANGER PERFORMANCE

Measurement Number	Specification Value	Burn			
		1st Burn	2nd Burn	3rd Burn	Coast Period
GQ 3459T	Temp, Super/Crit He/He HX Outlet	273*	343*	347*	196*
GQ 3463T	Temp, Super/Crit Fuel/He HX Outlet	468*	473*	475*	397*
GQ 3811T	Temp, Engine Interface Fuel	71.4	62°	63.7	N/A
GQ 3718T	Temp, Fuel Tank No. 1 Fuel Bulk	70.5	70.5	70.5	N/A
GQ 3719T	Temp, Fuel Tank No. 2 Fuel Bulk	70.5	72.0	72	N/A

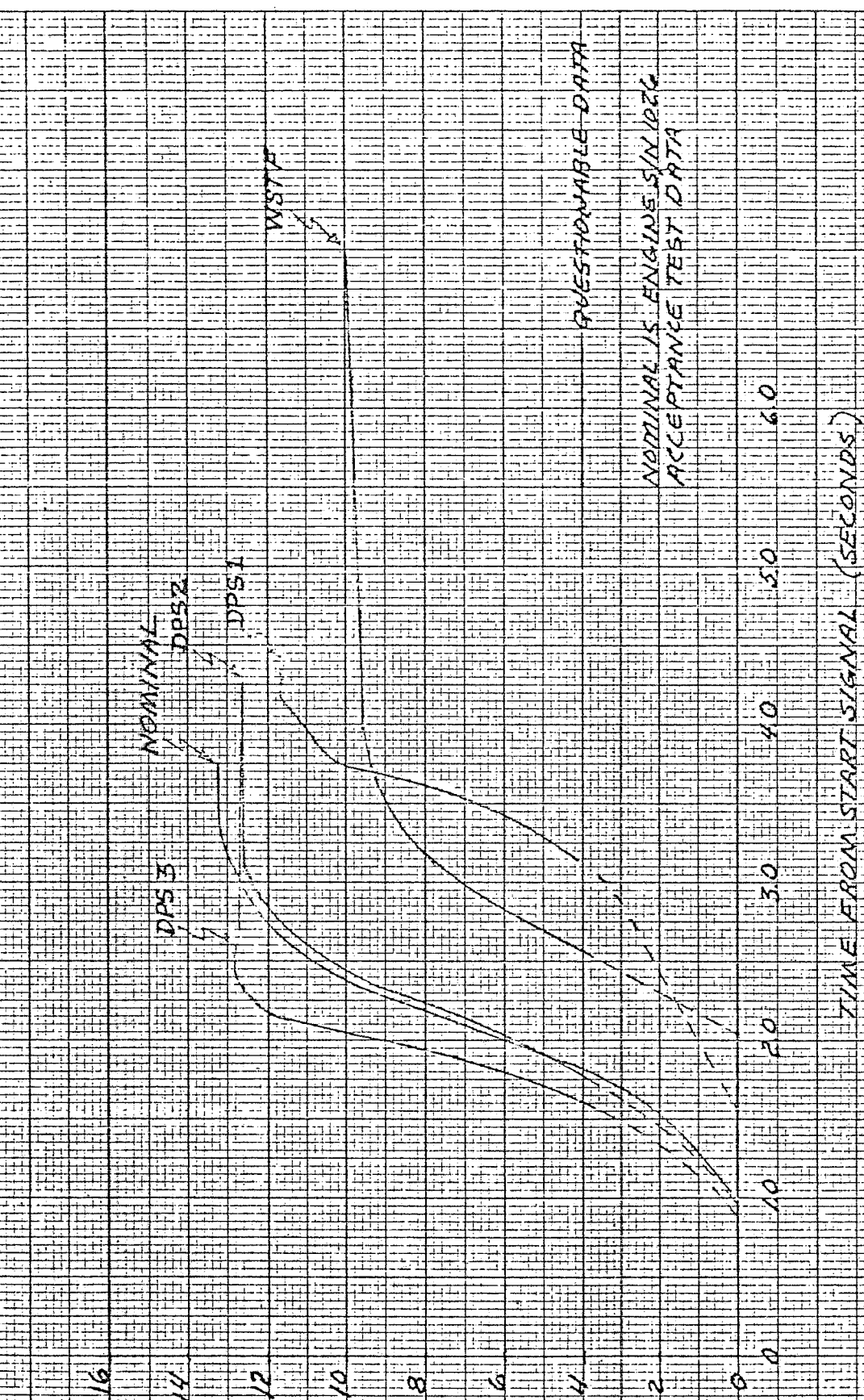
\*Minimum observed value during time period.

\*\*Specification constrains difference between GQ 3811T and GQ 3718T or GQ 3719T to be no less than 5°F.

FIGURE 1

DPS CHAMBER PRESSURE DURING START

MEASURED CHAMBER PRESSURE (PSIA)



QUESTIONABLE DATA

NOMINAL IS ENGINE S/N 1026

ACCEPTANCE TEST DATA

TIME FROM START SIGNAL (SECONDS)

FIGURE 2

LM-1 DPS SECOND BURN

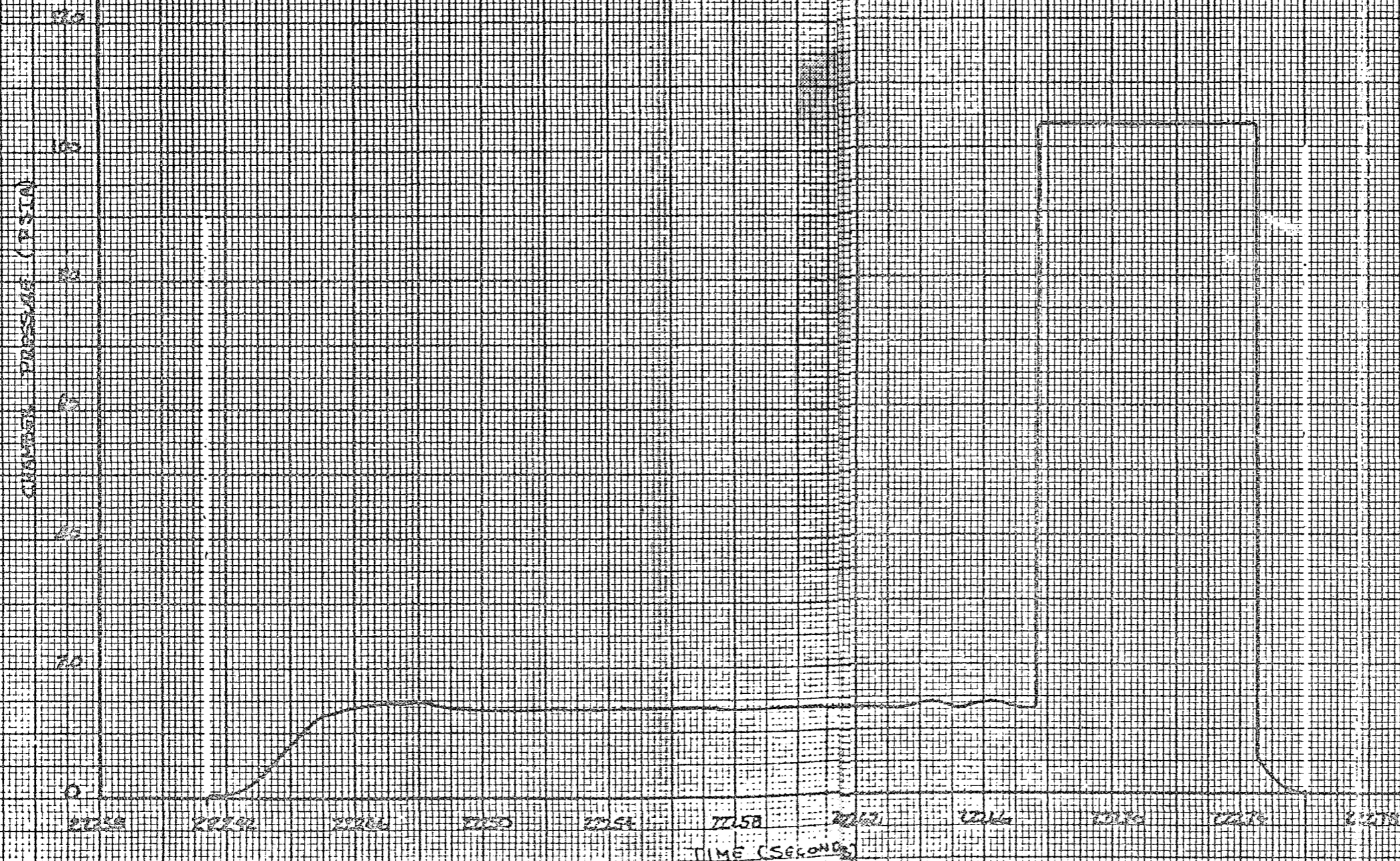
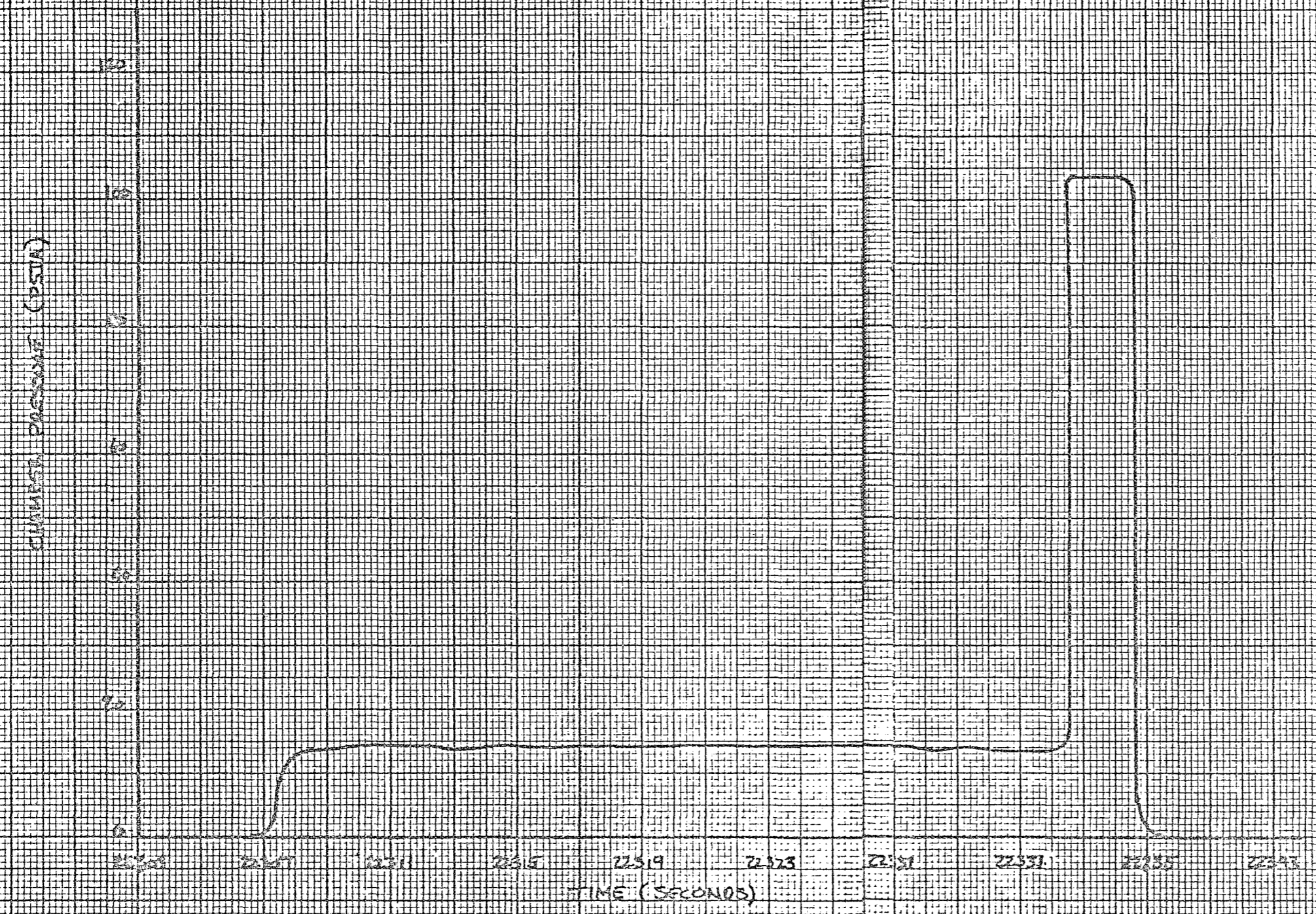


FIGURE 3

LM-3 DPS THIRD BURN



28

FIGURE 4

# DPS SECOND BURN THROTTLE SWITCHOVER

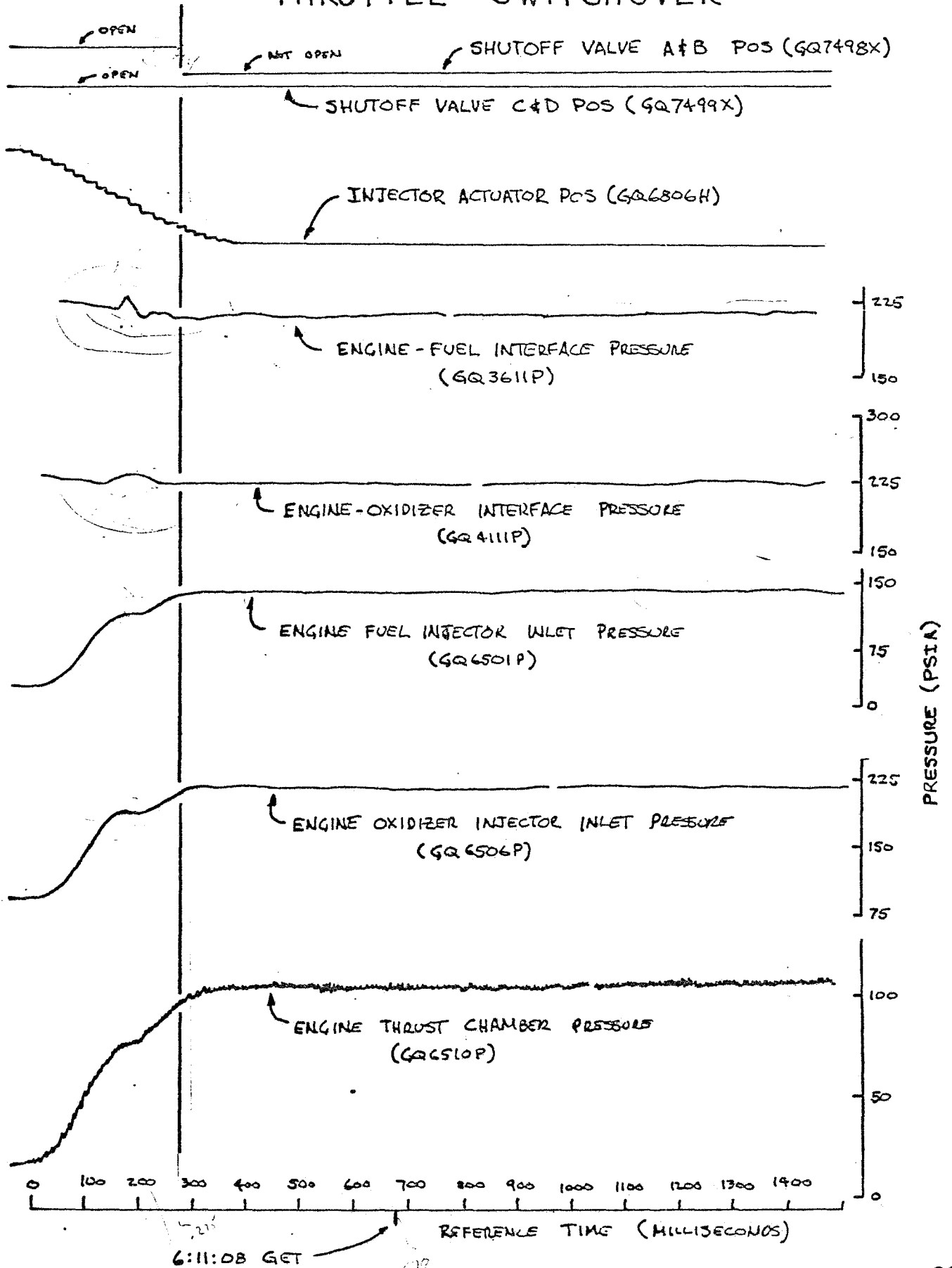


FIGURE 5  
DESCENT PROVISION SUBSYSTEM  
SUPERCRITICAL HELIUM SUPPLY TANK PRESSURE  
BURN 1

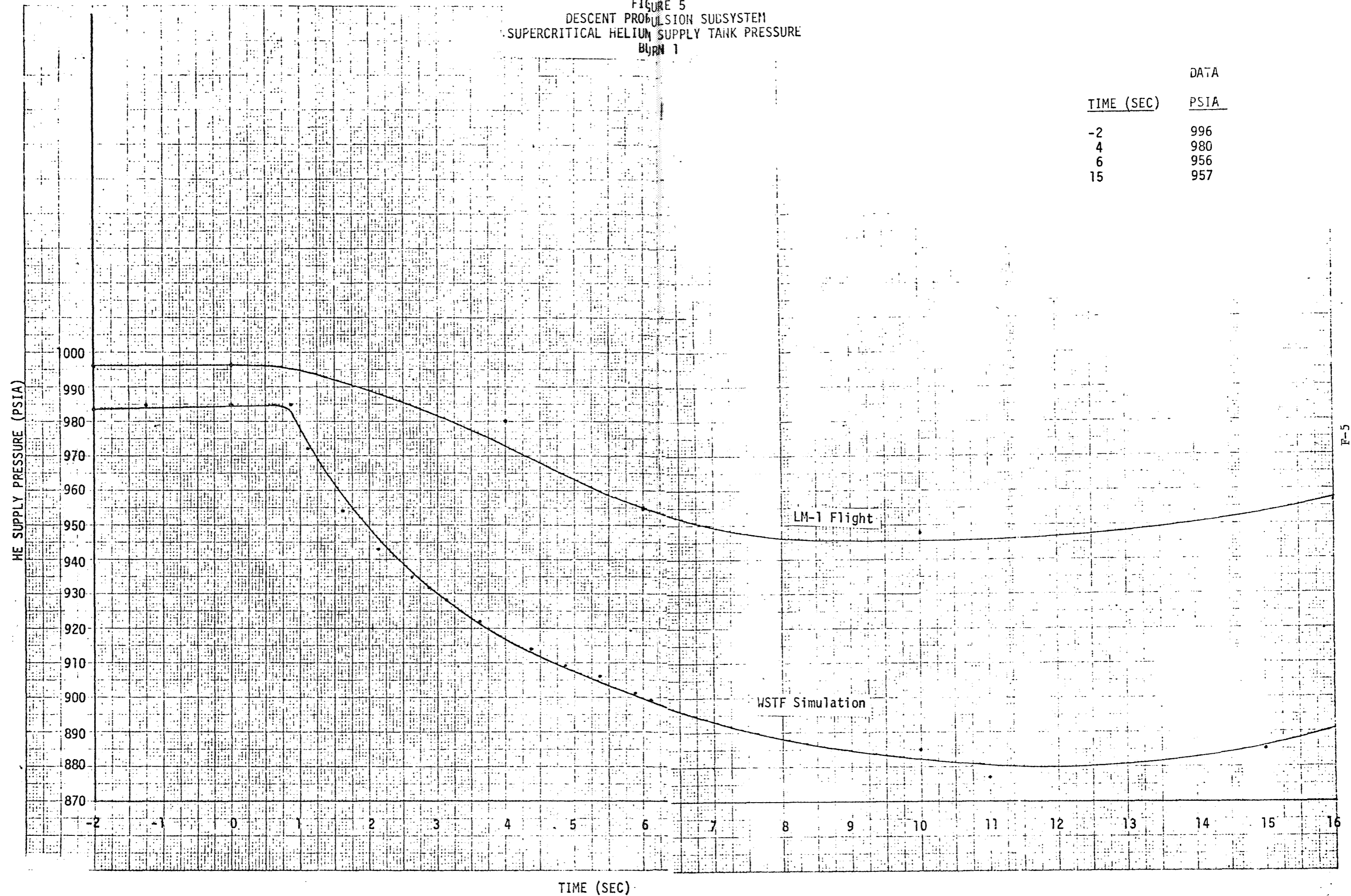


FIGURE 6  
DESCENT PROPULSION SUBSYSTEM  
SUPERCRITICAL HELIUM SUPPLY TANK PRESSURE  
BURN 2

LEGEND  
GYM =  $\triangle$   
RKV =  $\circ$   
GOLDSTON =  $\bigcirc$   
TEXAS =  $\bullet$   
CRO =  $\bullet$

DATA

Time, sec.	Psia
6:10:40	1004
6:10:52	1019
6:10:53	1019
6:10:56	1027
6:10:59	1035
6:11:02	1043
6:11:05	1051
6:11:07	1059
6:11:10	1067
6:11:11	1075
6:11:13	1083
6:11:16	1090
6:11:19	1098
6:11:21	1106

HELIUM SUPPLY PRESSURE, PSIA

1190

1170

1150

1130

1110

1090

1070

1050

1030

1010

990

970

950

6:10:40

50

6:11:00

10

20

TIME, SEC.

Predicted

Flight

FIGURE 7  
DESCENT PROPULSION SUBSYSTEM  
SUPERCRITICAL HELIUM SUPPLY TANK PRESSURE  
BURN 3

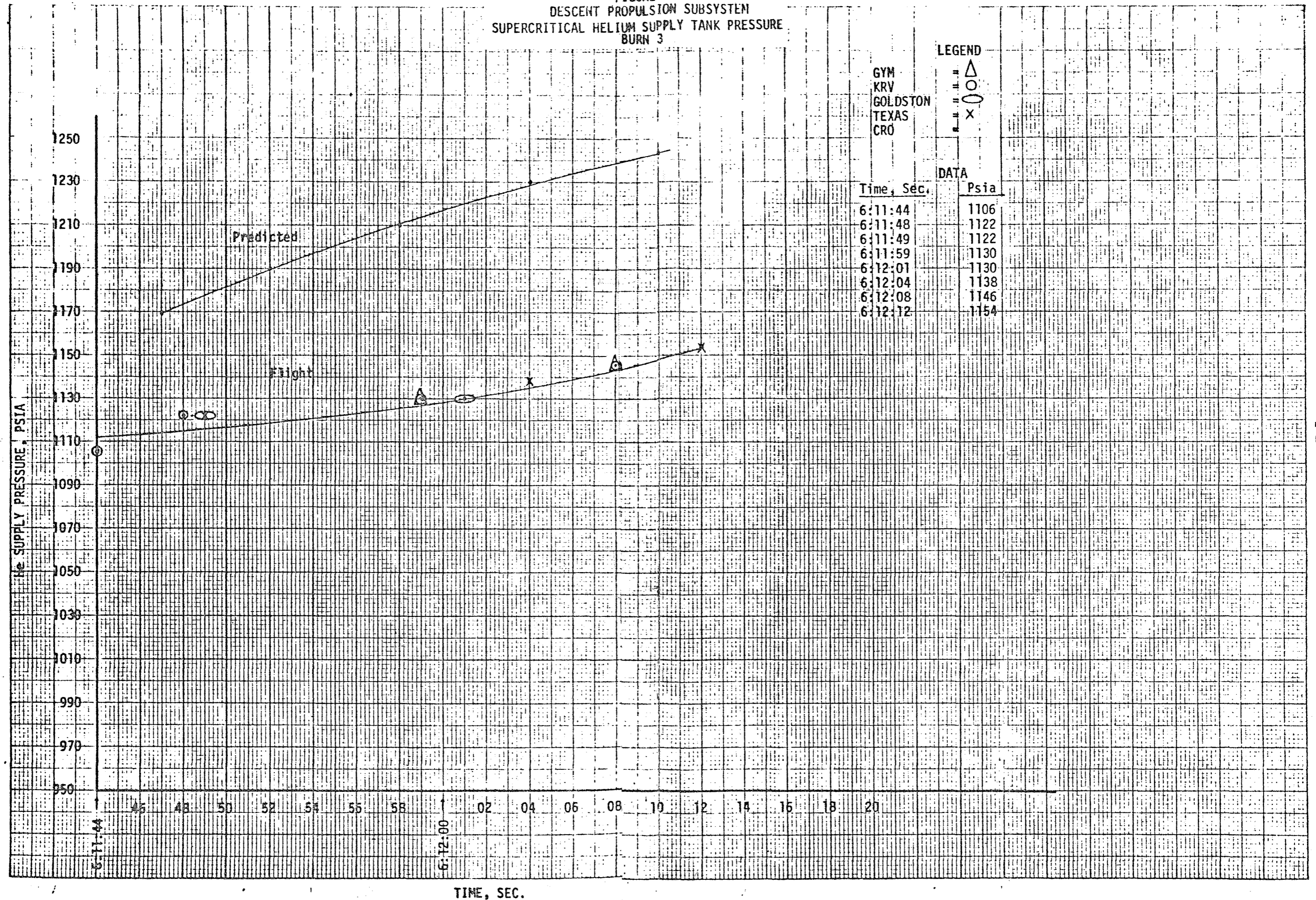


FIGURE 8  
DESCENT PROPULSION SUBSYSTEM  
SUPERCRITICAL HELIUM SUPPLY TANK PRESSURE  
BURN 1 THROUGH 3

NO SUPPLY PRESSURE, PSIA

LEGEND

GYM =  $\triangle$   
RKV =  $\circ$   
GOLDSTON =  $\bigcirc$   
TEXAS =  $\times$   
CRO =  $\square$

DATA

Time	Psia
3:59:35	996
3:59:45	980
3:59:47	957
4:00:46	972
4:04:38	988
4:06:11	988
4:24:03	988
4:31:32	988
4:32:35	996
4:39:14	996
5:32:47	1004
5:36:52	1004
6:05:20	1004
6:05:46	1028
6:05:46	1012
6:07:10	1012
6:08:32	1004
6:11:16	1090
6:11:19	1098
6:11:21	1106
6:11:27	1106
6:11:28	1114
6:11:49	1122
6:11:59	1130
6:12:04	1138
6:12:08	1146
6:12:12	1154

1150  
1140  
1130  
1120  
1110  
1100  
1090  
1080  
1070  
1060  
1050  
1040  
1030  
1020  
1010  
1000  
990  
980  
970  
960  
950

4:00:00

10

20

30

40

50

5:00:00

10

20

30

40

50

6:00:00

10

20

TIME, MIN.